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AN ADVANCED CONCEPT FOR THE OVERSEAS DCS.(U)
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DEFENSE COMMUNICATIONS ENGINEERING CENTER

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A digital, time-division-multiplex, multiple access system with primary communications via satellite is proposed for the overseas DCS. This proposed system could be built with current technology except for the space shuttle needed for launching, would require only four satellites, and would have sufficient capacity for the foreseeable future.

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AN ADVANCED CONCEPT FOR THE OVERSEAS DCS

AUGUST 1976

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FOREWORD

The Defense Communications Engineering Center (DCEC) Technical Notes (TN's) are published to inform interested members of the defense community regarding technical activities of the Center, completed and in progress. They are intended to stimulate thinking and encourage information exchange; but they do not represent an approved position or policy of DCEC, and should not be used as authoritative guidance for related planning and/or further action.

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I. INTRODUCTION

In this report we combine some ideas that have been developed by the Advanced Systems Concepts Branch of the Defense Communications Engineering Center [1,2] into a potential communications system capable of satisfying the needs of the Defense Department overseas in the post-1990 period. The system presented herein is designed as a trial balloon to aid in developing future plans, taking into account some of the latest technologies and system concepts.

The basic communications system proposed in this report is a digital time-division, multiple-access system with communications via satellite. Satellite capacity is dynamically shared among ground stations using the same satellite channel according to the needs of each station.

A primary consideration for the system is the flexibility. That is, the overseas bases of the United States should not be considered as absolute geographic locations for communications purposes. Primary control should ideally originate within United States territory. Day-to-day control should be as distributed as possible among differing sites to maximize survivability.

This report presents some specific communications systems problems, shows how the proposed system handles these problems, and discusses several alternatives to the system. Thus, modifications can be instituted as technology and the needs of the Department of Defense change.

The reader should keep in mind that the system is designed for the post-space shuttle era when satellites with much higher power capacity can be easily placed into the synchronous orbit. Space shuttle technology which is needed to provide economical launches is the only technology required for this system that is not actually available today.

This proposed system definitely has not been coordinated and decided upon as the path for the future DCS. Rather, it is a combination of advanced concepts for consideration and should be looked upon as a basis for discussion.

II. BACKGROUND

The present Defense Communications System has three common user networks. The first is the Automatic Voice Network (AUTOVON). This is the conventional telephone system with a precedence arrangement that gives high priority users preemption capability. It handles voice and other traffic which can be coded into a waveform and adequately transmitted on a nominal 4 kHz channel. The second is the Automatic Digital Network (AUTODIN). This network sends alphanumeric traffic between users at a rate of 2,400 b/s or 4800 b/s. User access to the AUTODIN is at various bit rates related by $2^n \times 75$ b/s with $n = 0,1....6$. The third network is the Automatic Secure Voice Network (AUTOSEVOCOM). This network transmits encrypted voice at three basic rates; i.e., 2.4 kb/s, 9.6 kb/s, and 50 kb/s.

Two additional common user networks are currently at the planning stage. One is AUTODIN II, a packetized digital network. Digital traffic in the form of record traffic or computer-to-computer data traffic can be sent through this network. First, the information is formed into packets of nominally 2,000 bits. These packets are then forwarded through the network from switch to switch on a store-and-forward basis until they reach their destination. The other planned common user network is the AUTOSEVOCOM II network. This should upgrade the AUTOSEVOCOM network with a single-rate network passing encrypted voice at 16 kb/s. In addition, the present DCS contains many dedicated circuits that carry voice and record traffic, mostly of the same type carried through the common user systems. Although there is a small amount of wideband service, most the service now provided by the DCS could be carried on the common user network. Dedicated lines are used for particular applications that require priority access to communications assets. Since the common pool has a non-zero probability of blocking, many commanders feel their critical circuits cannot share this common pool.

The common user network discussed in this report can handle a large number of specific classes of common user traffic. For the present and immediate future DCS we would need to include clear voice, data or record traffic at various rates, and secure voice traffic at 16 kb/s and 2.4 kb/s. In a first discussion, inclusion of many classes of traffic obscures the basic understanding of system operation. Thus for the specific discussion we shall only consider two traffic classes - voice (and other traffic that can be carried on a voice channel) and data. The transmission in this system is all digital; therefore, the voice must be digitized. For the most conservative capacity estimates we consider this to be PCM at the rate of 64 kb/s. Since this is the standard pulse code modulation rate currently used by the common carriers in telephone systems and it is high enough to handle all classes of traffic now put through telephone lines consideration of a 16 kb/s network with 16 kb/s service could have been included as an additional class but would just add confusion, and hence will not be considered further. Designing a system with these other traffic classes is really no more difficult, just slightly more complicated and would tend to obsure the main issue of the report.

For the purpose of this report we will assume that all data traffic is packetized with a packet size of 1,000 bits. Other packet sizes or another service which is basically circuit-switched at some low bit rate, such as 4.8 kb/s, could be added into the network; but these also add confusion and therefore will not be considered. The system, however, would be essentially the same. As more services are added, more data must be passed around to indicate the demand for service and signaling must be passed to give the connectivity. Our example system with one class of virtual circuit-switched users and one class of store-and-forward, packetized users demonstrates all the principles.

DCS traffic overseas originates from a small set of specific geographic locations. Although the locations will be changing from time to time as the United States gives up certain bases and acquires new ones, the structure will be fundamentally stable at any time. For example, at present we have forces at a number of places throughout the United Kingdom. The map and the termination file* of the DCS show that the originating locations for traffic can be grouped into 10 or 12 specific geographic areas within U.K. Each area is compact enough so that all system connections within that area can be brought to a central location by phone lines or a one-shot microwave link. Thus, these areas could be set up as 10 or 12 geographic nodes without the need for additional relay sites.

*The termination file is the listing of the locations of end points of each channel in the DCS with the type of service provided over that channel.

III. BASIC SYSTEM CONCEPTS

1. BASIC SATELLITE PARAMETERS

Since our postualted system relies on satellites for most* of the communications capacity, we will consider some basic parameters of military communicatons satellites. The DSCS III satellite, currently under development, operates in the military satellite communications band in the 7 and 8 GHz region. The bandwidth of the satellite is ½ GHz, and is divided into six active communications channels, using a total of 360 MHz, plus guard bands to fill the 500 MHz capacity. Four of the six bands are 60 MHz wide. We shall assume a 60 MHz bandwidth in our discussion as a practical number. A different bandwidth would of course be satisfactory. Should other technical issues require a different bandwidth, this would not change the basic concepts of the system.

The most common modulation system for digital transmission through satellites is 4-Phase PSK. Such systems get approximately 1½ bits per Hertz of bandwidth. Thus a 90 Mb/s signal could be used to communicate through the 60 MHz channel on the satellite we have chosen as standard. Such channels will be shared among several ground stations in a time-division multiple-access mode. The nominal system therefore has 90 Mb/s transmission channels and 64 kb/s individual voice channels, which are digitized and transmitted at the 90 Mb/s rate. If we assume that approximately 29% of the bits would be needed for framing and timing, we can still get 1,000 nominal voice channels on one transmission channel. In our example system we will use these numbers. As pointed out previously, our common user system will transmit both voice and data -- packetized in 1,000 bit packets.

2. DEMAND INFORMATION REQUIREMENTS

The present Defense Communications System has five precedence levels for voice and five for data. Therefore there can be 10 different demands on each station. The DCS must be capable of transmitting voice in each precedence class and data packets in each precedence class. In the proposed system each station must inform the other stations sharing a satellite transmission channel of its demands. Thus for control purposes, each station must send 10 numbers to all the other stations to tell them how many voice channels or data packets it has in each precedence class for transmission.

One possibility for sharing this demand information would be for each ground station to transmit its demands via a terrestrial radio relay on a regular basis. The technique used to pass this information could be those developed under the ARPA sponsored packet radio study [3]. The carrier

*Because satellites are a prime target, a backup terrestrial network adequate for emergency communications in wartime should be maintained.

frequency band used would depend on the specific geography and available allocations. The error protection of the packet radio is sufficient for very reliable HF transmission except during complete blackout following a nuclear blast. Any terrestrial system that can pass one to two hundred bits per second with high reliability is possible for the demand data network.

For the data itself, let us consider some specific numbers. Suppose that at the beginning of each second each ground station determines the number of active (off-hook) voice circuits in each precedence class, and the number of data packets that have been received in each precedence class. The station then broadcasts these 10 numbers over the appropriate terrestrial channel with an error correcting code so that the information is received by the other stations in the transmission channel group with almost zero error probability. Except possibly for the very largest military bases, the number of channels needed in each class will never exceed 256. Thus, an 8-bit word for each number is adequate. This means that only 80 bits of data need be passed each second in order to give the demand. To relate demands to stations, a 10-bit station code can be added. This means that a total of only 90 bits of information are required each second. If, for example, there are more than 256 channels in, say, the ROUTINE class, then instead of 8 bits, 9 or 10 may be required for identity. Still, less than 100 bits in the data exchange are required. Two types of voice channels and two types of data packets would still only double the number of bits required. There is no problem sending 100 or 200 information bits once per second with considerable error correction even over an HF channel. Thus, our proposed system keeps communications over a terrestrial radio grid going at all times in order to share demand data. Should the satellite be lost, this terrestrial grid could be used for emergency communications of other sorts. As shown below, the signaling sent over the satellite also contains the demand information discussed in this section. Thus the earth stations have a check on the accuracy of the terrestrial communication network so that the reliability of the emergency network is assured. This report does not address the issues of such an emergency communications network.

To sum up the proposed system, a number of ground stations would share the satellite communications channel in a TDMA mode. The ground stations would inform one another of their communications demand via terrestrial radio.

3. THE COMMUNICATIONS CHANNEL

Once the ground stations have the demand information they can compute the time slot allotted to each in the TDMA system. The system must be sized so that all FLASH and FLASH OVERRIDE calls and messages can have channels at any time without blocking. This situation must be true for even the most communications-intensive war scenarios. Beyond the FLASH and FLASH OVERRIDE calls and messages, an algorithm must be set so that the various ground stations share the transponder capacity in a reasonable way. Obviously, conversations have some priority over data packets, since a data packet can be briefly stored and then forwarded without disturbing the message flow. As we shall see later, it is not difficult to size a system using four satellites

to give virtually nonblocking performance even for ROUTINE traffic as projected for the period under consideration in this report.

We have defined a system where once a second each ground station measures its demand and then transmits the demand to those other stations sharing the satellite transponder. With this information each ground station computes its available time slot and then communicates by sending burst of traffic in the time slot allocated. If 1 second is allowed for transmission and receipt of the demand information and another second for computation of the time slots and setting the timing on the transmitter, then each station has set its capacity based on demand that is only 2 seconds old. With respect to the time span of most voice conversations and with data packets of 1,000 bits, this is unusually up-to-date information.

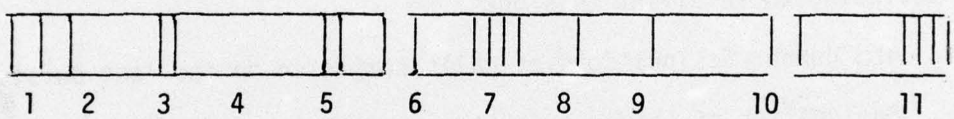
In a time-division multiplex-access system time is divided into frames of specific, uniform length. During each frame each ground station is allotted a subframe time, and during that subframe the ground station sends its traffic in a burst. In our system the subframe timing is computed by the algorithm discussed in the previous paragraph. The basic time frame must be selected so that each station gets a reasonable amount of time to send traffic. Overhead is always required for synchronization; thus if the burst is too small the overhead rate will be excessive. On the other hand, if the main time frame is too long, excessive delay is introduced into the system. Traffic from the various connecting data, voice, and other terminals comes in more or less continuously. For each frame, the traffic must be organized for the burst and then the ground station must wait its turn before transmitting its traffic. Consequently, a two-frame delay is possible at each ground station.

In a satellite system there is an inherent quarter-second delay due to the transit time to and from the satellite. The frame size must be such that no appreciable additional delay is introduced. As an example, assume that the basic frame size for a burst is 1/64 second. This means that an additional delay of about 1/32 second added to the quarter-second delay is not really appreciable. However, other delays in the system may make the 1/32 second delay excessive. If so, then a shorter frame cycle could be chosen. These numbers are just an example and are not critical to the basic design of the system.

Digitized voice and data packets from local terminals arrive at each earth station at times not synchronous with the burst timing. Thus each earth station must have registers for storing and formatting the bits as they arrive. With the number we chose, both the digitized voice and the data packets are 1,000 bits. Thus, the storage registers will be 1,000 bits wide. Each active voice conversation will be assigned a particular register. As data packets come in they will be stored in registers appropriately set for store-and forward operation. The information in these various registers will be fed into the main bit stream that drives the transmitter at the 90 Mb/s rate. Voice registers will be erased as soon as the information is transferred to the transmitter. Data registers will be held until confirmation signaling is received indicating that the data packet has been received without error. Then the data packet can be erased.

In a telephone conversation one party or the other is silent approximatly half the time. Consequently, the voice registers will be empty approximately half the time. It is fairly easy to construct an algorithm that determines whether or not there has been voice activity in the particular 1/64th of a second period that the register contents represents. If there is no activity, there is no need to take up space in the transmission burst. The signaling system described below shows how to use speech non-activity for data transmission. With this system if the number of data packets per second is not much greater than 32 times the number of voice channels in operation, then the data packets would on the average be put into the transmission stream during voice silences without the need to reserve time for these packets. The use of the statistics of voice silences to get 2n or more conversations in n voice channels has been studied extensively [4]. In the system proposed herein data packets can also be transmitted during voice silences without adding extra channels for the data network. A typical format for the data transmission might be shown in Figure 1.

Figure 1. Communication Burst Format



1. Bit pattern to calibrate receiver to transmitter phase
2. First 1000-bit segment from first active voice channel
3. Frame bit
4. Segment (1000 bit) from second active voice channel
5. Frame bit
6. Remaining active voice channel segments separated by frame bits
7. Bit pattern for end voice start packetized data
8. First data packet with address header and check sum at end
9. Second data packet
10. Remaining data packets
11. Bit pattern indicating end of burst.

4. SIGNALING FOR THE COMMUNICATIONS CHANNELS

A burst of traffic such as that of Figure 1 will contain voice segments and data packets destined for several different receiving ground stations. Thus each receiver must be informed via some form of signaling in order to know which segments and packets to place in registers for transmission to terminals connected to that receiver. The signaling scheme described in this section was designed to give all required information for routing plus enough redundant information so that any receiving station could monitor all performance of those transmitters

whose outputs were coupled down to that receiving station. This helps provide the distributed control that is built into the system.

The signaling can be sent on a common signaling channel or it can be sent inband. In a TDMA system the inband signal would be sent between the calibration bits (1 of Figure 1) and the first information segment (2 of Figure 1). For common channel signaling, a separate band must be set aside. These transmission details are discussed in Section IV-3 below. In this section we present the required signaling data.

A possible set of signals to define the traffic of a burst such as that of Figure 1 and to give monitor information is the following sequence of numbers:

1. The number of 64 kb/s voice channels that are active for this burst.

2. The number of data packets that are included in the burst. Receipt of the numbers (1) and (2) tells the receiver how long the transmission bursts will be. Correct receipt of these signals can be checked against the voice data boundary (7 of Figure 1) and the end of burst (11 of Figure 1) markers.

3. The total number of voice calls in progress, i.e., all established calls including those silent this burst.

4. The number designations of calls completed on the last burst.

5. Designation of channels for those of the transmitting station's previous call requests that have received a favorable response. These requests are then moved to establish channel status.

6. Designation of channels for those requests from other transmitting stations for establishment of a voice channel to this transmitting station when the requested connection is made. These also contribute to the number of established channels. At this point receiving stations have a complete description of the established voice channels. The list includes those established on the previous burst minus the completed calls (4) plus the new calls (5) and (6). The total number of calls on the list should equal the number given in (3).

7. The channel numbers of the calls active this burst.

8. Requests for connections for newly dialed calls.

The use of the signaling set to establish a full routing table is given in the example of Table I. Following the numbers of the previous paragraph the signaling set for the nth burst is:

For item 1. 5 is transmitted
2. 9
3. 11
4. 2, 5, 9
5. R1, R3
6. 539-4103, 4110; 690-1191, 2601
7. 1, 3, 6, 8, 10
8. 391-2407, 1105

In Table I we first show the listing of the voice channels for the $(n-1)^{st}$ burst because that is needed to construct the table for the nth burst. Except for the asterisks in the column header voice channels completed, the table for the $(n-1)^{st}$ burst is filled in before that burst is received and also before the signaling listed above is received. When item 4 of the above signaling set is received, the listing for the $(n-1)^{st}$ burst is completed.

Starting from the $(n-1)^{st}$ burst listing and the signaling set above, each receiving station makes up the nth burst section of Table I as follows. Items (1) and (2) tell how long the nth burst will be. They are listed on the left side of the table to show how many voice segments and data packets there will be in the burst. This information gives a check on the bit count between framing bits as shown in Figure 1. Item (3) tells the receiver that 11 lines in the table will be needed to list the data on the established channels. Item (4) is the first item that allows the receiver to begin generation of the table for the nth burst. This item states that calls listed as channels 2, 5, and 9 on the $(n-1)^{st}$ burst were completed. The receiver deletes these three calls from the list and copies over the call information from the $(n-1)^{st}$ burst. Thus call 3 on the $(n-1)^{st}$ burst were completed, the first 7 calls of the nth burst are copied with the gaps closed.

Item (5) of the signaling says that call requests R1 and R3 are now active calls. Thus lines 8 and 9 in the nth burst are calls R1 and R3 from the $(n-1)^{st}$ burst. Item (6) lists calls connected in response to requests from other transmitting stations. For the previous burst, and probably several before, these were listed as requests in the table of their respective calling stations. The first would have been on the 539 station table and the second on the 690 table. Listing the complete number in item (6) gives a check. For example 539 R2; 690 R4; might have been just as good a signal. These two calls are listed as established calls 10 and 11 under the nth burst listing of Table I.

Item (7) lists the active calls. The receiving stations for these called numbers must have register space ready to receive the information bits for transmission on the appropriate telephone. Item (8) gives the data on the new call request, now listed as R2. Since R1 and R3 from the previous burst signaling become active calls, old R2 becomes new R1. The new request takes the R2 designation.

TABLE I. VOICE CHANNEL LISTING FOR TRANSMITTING STATION 437

	Voice Channel Number	Calling Number	Called Number	Voice Channels Active	Voice Channels Completed
$(n-1)^{st}$ Burst	1	3457	271-3684	*	
4 Voice Segments	2	2731	387-9275		*
8 Data Packets	3	3129	243-3068		
	4	4072	539-4287	*	*
	5	3264	775-3208		
	6	4543	494-8607	*	
	7	2579	229-4486		
	8	2076	690-3125		
	9	3175	847-9290	*	*
	10	4233	587-2175		
	R1	2101	620-4329		
	R2	3127	539-4907		
	R3	2945	471-3792		
nth Burst	1	3457	271-3684	*	
5 Voice Segments	2	3129	243-3068		
9 Data Packets	3	4072	539-4287	*	
	4	4543	494-8607		
	5	2579	229-4486		
	6	2076	690-3125	*	
	7	4233	587-2175		
	8	2101	620-4329	*	
	9	2945	471-3792		
	10	4110		*	
	11	2601			
	R1	3127	539-4907		
	R2	1105	391-2407		

In Table I we have no information on the packetized data except for the number of packets being transmitted. Since data packets contain their destination addresses in the header, there is no need to forward this information in the signaling channel. Each receiver reads all headers and stores only those packets for terminals attached to that receiver. Confirmation signaling could be sent back through the signaling channel. Operation of the packets would be the same as for any store and forward packetized system such as ARPANET or AUTODIN II.

5. SYSTEM CONTROL

Let us consider communications system properties such as control, vulnerability, and survivability to determine the attributes of the proposed system. By using this baseline system a better appreciation can be obtained of the significance of various parameters relative to different systems. Access control in this system resides in an algorithm which is utilized at every ground station. Thus access control is completely distributed. A central management control station can have each ground station change its algorithm from time to time. However, for normal operation each station has a proper algorithm for computing the burst lengths. The satellite capacity is well utilized and there is no need for a central control station to constantly tell each station how many channels, that is, how long a time assignment, it has per burst. A fully distributed control is least susceptible to interference, due either to equipment failure or to an enemy jammer.

With the proposed system if one station should somehow misapply the algorithm or if the clock should be off and the timing is wrong at that station it will in turn jam other stations. Performance must be constantly monitored to prevent this jamming. Since all information is transmitted by satellite except the demand control information, every station communicates with nearby stations. Some of the energy from the satellite transmitting antenna will radiate back to the earth station that beamed up the signal. Consequently each ground station can monitor at least part of its own transmission and see how its burst fits in with the bursts of others. Since all stations use the same algorithms, all transmissions should fit together. A station seeing that its transmission is not fitting with the others knows there is something wrong. Furthermore, the other stations receiving that transmission will also immediately know something is wrong and can then all send messages to the offending station to point out the error.

For central management information, the basic traffic operations and errors in physical performance would be cataloged at a central station. A directive satellite antenna could bleed a small amount of power from every transmission and direct it toward a large ground station located in secure territory. This ground station could monitor the performance of all transmissions and, since it receives the signaling channels, could also keep all traffic records. Since such a ground station could have a very large antenna, very little satellite power would be required for the monitoring function. Where frequencies are reused in different parts of the world, using different antennas on the same satellites, it might be necessary

to have two monitor ground stations for the frequencies that were used twice. If more frequency usage is incorporated, then more monitor ground stations would be required. For an Atlantic satellite handling intra-Europe and Europe-to-CONUS traffic the monitor station could be within CONUS. All changes of control algorithms and all control and monitoring of the system would be within CONUS; therefore, large data bases outside the United States would not be needed. The East Pacific satellite could also be controlled from a CONUS station, while a West Pacific satellite would be controlled from Hawaii. An Indian Ocean satellite could be controlled from East CONUS or from Hawaii via a satellite-satellite link.

IV. SYSTEM PROBLEMS AND PROPOSED SOLUTIONS

1. SATISFACTION OF REQUIREMENTS

The communications requirements projected for the period during which the proposed satellite system would be implemented should be taken into account. Specifically, let us consider the DCS in Europe, an Atlantic satellite, and how communications within Europe and from Europe to other theaters could be handled by the system. By Europe we mean all the European DCS as presently constituted, including Tehran, Bahrain, Turkey, and points in North America, as well as Europe proper. The specific numbers that we consider here were taken from a listing of all the telephone and record channels within the DCS as constituted in 1975.

The present map of the European DCS shows about 190 bases that generate traffic and about 27 communications relay stations. Since many bases are quite close to one another, especially in Germany and England, the communications could be consolidated to 60 or 70 satellite terminal stations connected to all users by highly reliable microwave links or base cables. No off-base relay stations and no tandem switches would be required.

From the data base we find that the largest use at present is intra-Germany voice traffic. As a specific example, let us look at Vaihingen and the nearby Robinson Barracks at Stuttgart. These two bases are easily within line-of-sight microwave communications of one another. Adding together all the circuits from these two places we find that there are 403 dedicated voice circuits to other places in Europe, and 67 AUTOVON access trunks. There are 259 teletype circuits at 75 baud or less, plus 7 higher data rate circuits to points within DCS in Europe. There are also 12 accesses to AUTODIN at various bit rates. There is one 15 KHz wideband circuit from Stuttgart to Frankfurt and two 120-scan facsimile circuits.

To the CONUS there are only 10 dedicated voice circuits and 28 low data rate teletype dedicated circuits. In the common user pool there is one AUTOSEVOCOM intertrunk switch and four AUTOVON access lines to CONUS. This represents the total present DCS communications of this one base area.

If we consider all the data circuits to be used full time, and their data collected at the ground station to form packets as described in the section above, and if we consider all voice circuits as full time without the 50% or less duty cycle that voice silences introduce, we still find that this very large base area would require only about 1/2 the capacity of one satellite transponder. Thus if we assign 1/2 of a transponder to this base, we have at least double the present capacity for our future communications requirements. Only two other bases have traffic demands even close to that of the Vaihingen-Stuttgart area: Air Force Europe Headquarters at Ramstein and Army Headquarters at Heidelberg. All other areas provide far less traffic and have far fewer circuits over which to direct their traffic.

The entire present European DCS traffic would generate only about five transponders worth of traffic if all circuits were busy 100% of the time. With the conservative estimate that voice silences give a 50% duty cycle, and that even in the busy hour only half the circuits are in use at any one time, five transponders could handle a four-fold increase in DCS Europe traffic.

As mentioned earlier, DSCS III will have six transponder channels of the type considered. If both vertical and horizontal polarizations were used, a satellite could handle 12 transponders of the type considered without additional geographic frequency reuse. With a very generous projection of future traffic, less than one-half of the satellite capacity would provide all our communications of the type now carried in the DCS.

To show a more detailed situation for some of the smaller bases, we examine the bases in Iceland and the United Kingdom and checked each termination to make an accurate determination of traffic carrying capacity. Table II summarizes the results of this analysis. If nearby bases were clustered, only about 14 ground stations would be needed. This clustering left out a few sites with very few terminations. Circuits from these sites to CONUS or across the English Channel were grouped together as the 15th line in the table. From this count there are 647 voice circuits from ground stations in UK-Iceland to others in UK-Iceland and the rest of DCS Europe. Circuits among bases that are clustered are not counted, but intercluster circuits are.

The teletype and data circuits, when all operating together, can only generate 203 data packets per second for transmission to other ground stations within Europe. Since a voice circuit is equivalent to 64 packets per second, this adds less than the equivalent of four voice channels. To account for AUTOVON and AUTODIN we assume that half the traffic is to other points in Europe and half to CONUS. This adds 86 voice circuits for AUTOVON and only one (17 packets) for AUTODIN. Thus the equivalent of 738 voice channels go from this large segment of DCS to other parts of DCS Europe. The traffic to CONUS is only equivalent to 139 voice channels. The total traffic from Iceland and the United Kingdom would only require one transponder for approximately four times the capacity of the present day DCS.

Under the assumption that all voice channels would only operate in a half-duplex mode, five transponders could provide dedicated circuits to twice as many as now have them. In actual fact, the duty cycle is less than one-half and there would be absolutely no blocking for a four-fold traffic increase. A more appropriate scheme would be to assign only about three transponders rather than five for expanded DCS traffic. These specific design details are not discussed in this report.

There is considerable interest in adding many communications services to the military communications system. The Worldwide Military Command and Control System will, when fully developed, need considerably more communications capacity. There are plans to relay considerable intelligence data back to the CONUS for processing rather than using the few narrowband circuits for

TABLE II. TRAFFIC FROM DCSEUR - NORTHWEST SECTOR

	EUR Voice Circuits	EUR Packets	AUTOVON	AUTODIN Packets	CONUS Voice Circuits	CONUS Packets
1. Iceland West (Keflavik)	46	17	8	1	41	11
2. Iceland East (Hofn)	26	2				
3. UK - Scotland (Thurzo)	8	7	1			
4. UK - Scotland (Edzell)	21	9	3	1		2
5. UK - N. Ireland (Londonderry)	17	16	7	4	3	4
6. UK (Fylingsdales Moor)	19	7	1		4	7
7. UK (Martlesham Heath)	116	1	15	2		
8. UK (Wethrsfield)	74	3	11	2		
9. UK (Lakenheath-Mildenhal)	54	4	35	4		1
10. UK (Alronburg)	36	6	11	2		
11. UK (Chicksands)	3	28	10	5		14
12. UK (Croughton)	84	71	26	3	1	7
13. UK (Northwood)	16	1	1	1		1
14. UK (London, Hillingdon)	120	22	42	6		2
15. Other UK out of UK	7	9		2	2	12
	647	203	171	33	51	61

data processed in the field as we do today. In addition, our ground mobile forces when put into a forward area will communicate back to fixed bases over an SHF satellite. These items were all studied by the military satellite office [5]. They asked what would be the total satellite communications requirement in the 1990's if every commander had all the resources that he felt he needed and could afford. The specific data are classified, but a scan of the totals for our long-term needs shows that in no scenario did the total requirement exceed 300 megabits. The 300 megabits requires only four satellite transponders. Adding these four to the approximately five required to quadruple the present DCS capacity still leaves three transponders available on a fully loaded satellite.

At the present it is not economical to orbit a satellite which would carry 12 of these 90 megabit (60 MHz) transponders and provide adequate power for operation with various sizes of ground stations. However, when the space shuttle becomes available, and it should be available before a system of the type discussed here could be fielded, there should be little problem putting up payloads adequate to give the capacity discussed herein. Large solar cell panels could easily collect enough power to handle more than the 12 transponders. Since some frequencies could be used twice there is little doubt that we could handle all the communication needs of the military in a few satellites. Four is the number usually discussed for full earth coverage. We would be more likely to fly two satellites in nearby orbits for reliability, in case one failed, then we would for the required capacity to handle our needs. When we have the power in orbit available, the system discussed herein could easily handle all now projected communications requirements.

2. SATELLITE ANTENNA CONSIDERATIONS

In a military satellite system the uplink antenna (i.e., the satellite receiving antenna) pattern should have a very narrow beam so that only those ground stations which are to communicate with the satellite are in the beamwidth. Then a jammer must get into the narrow beamwidth, where it is fairly easy to locate. The system was designed so that geographic location of the ground stations would be an important consideration in the sharing of a time-division multiple-access channel. The channel is shared by stations clustered together for transmitting their data up to the satellite. However, ground stations in a clustered geographic area will want to communicate with stations all over the world, even though most of the traffic will be between nearby stations, if not necessarily those in the same cluster. Thus, the downlink antennas in the satellites will probably require somewhat larger beamwidths than the uplink antennas.

Downlink antenna beamwidth is restricted primarily by the signal strength required at the station on the ground. The main power consideration in a satellite is the downlink power. Thus, the satellite transmit antennas should have as narrow beams as feasible to conserve transmitter power. They probably must have a wider beam than the uplink antennas so that a station can communicate with a larger group of stations than those in its own uplink cluster. If we consider the satellite uplink antenna to have a 1° beamwidth,

then the area included in our present DCS Europe (i.e., Europe including Iceland, Northern AFrica, and the middle East) can be covered by five beams with some overlap between the beams. Five uplink clusters using three transponders is a feasible grouping of stations as discussed below. As point out above, this would give us double the present DCS Europe capacity.

For the downlink, all three of these transponders would transmit through an antenna pattern that covers the entire DCS Europe area. Thus, every European station can receive from every other European station. At present this is required because there are channels between Asmara in Ethopia, England, and Iceland. The whole area must be covered in the downlink if the present communications are to be included in this future plan.

Figure 2 shows a map with the various areas for approximately 1° to 2° beams in Europe-Africa-Middle East from an Atlantic satellite. The northern and eastern beams elongate because of the curvature of the earth. Because of the smaller traffic demand from the southern three areas (III, IV, V) these could share one transponder. The other two clusters (I, II) could each have a complete transponder. The downlink antenna beam could cover the whole DCS Europe area for each transponder. A second beam on downlink, as well as an uplink beam, could cover the area of CONUS as shown.

From the DCS circuit termination data discussed in the previous section we see that about 1/6 of the traffic is between Europe and CONUS while 5/6 is intra-Europe. Thus the satellite receive antenna patterns for areas I and II of Figure 2 would be connected to downlink antenna patterns covering all of DCS Europe for 5/6 of the time and covering region VI (Eastern CONUS) 1/6 of the time. Figure 3, shows the timing of the traffic bursts for area I. Area II would have a similar pattern except that the absolute time would be rotated so that the respective bursts of traffic to CONUS would not overlap from areas I and II. The line between the Europe bound traffic and the CONUS traffic is set by a switch within the satellite as discussed in [6]. The timing for the switching within the TDMA frame would be set from the master spacecraft control station. Normally the line might move through a regular sequence during the day to give more Europe-CONUS time during the joint busy hour and more Europe-Europe time during the Europe only busy hour. Another arrangement could be made for bulk data transfers at the off hours. The signaling channel would have a space for the master control station to inform appropriate ground stations of any switch other than the programmed diurnal variation.

Each ground station segregates its traffic in Europe-Europe and Europe-CONUS segments. The algorithm for dividing the time among ground stations sharing a TDMA frame discussed in section III-3 above is then used by these stations to divide up the allotted time. The time segments are assigned to each channel by the algorithm. These segment lengths, as shown dotted in Figure 3, will be reassigned every few seconds as discussed above.

For ground stations in areas III, IV, and V, the master uplink time is only part of a TDMA cycle for each area. As shown in Figure 3, uplink antennas

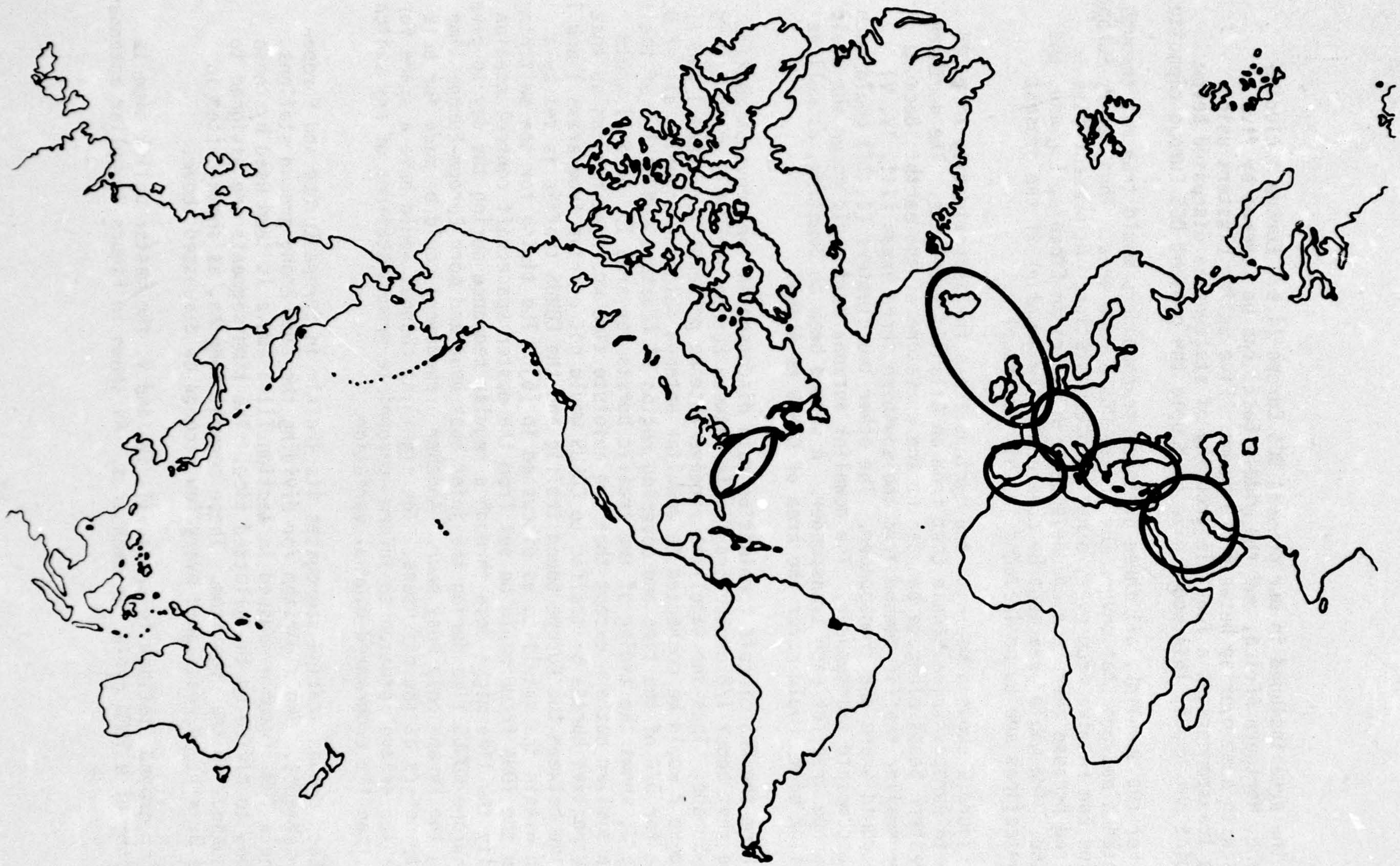
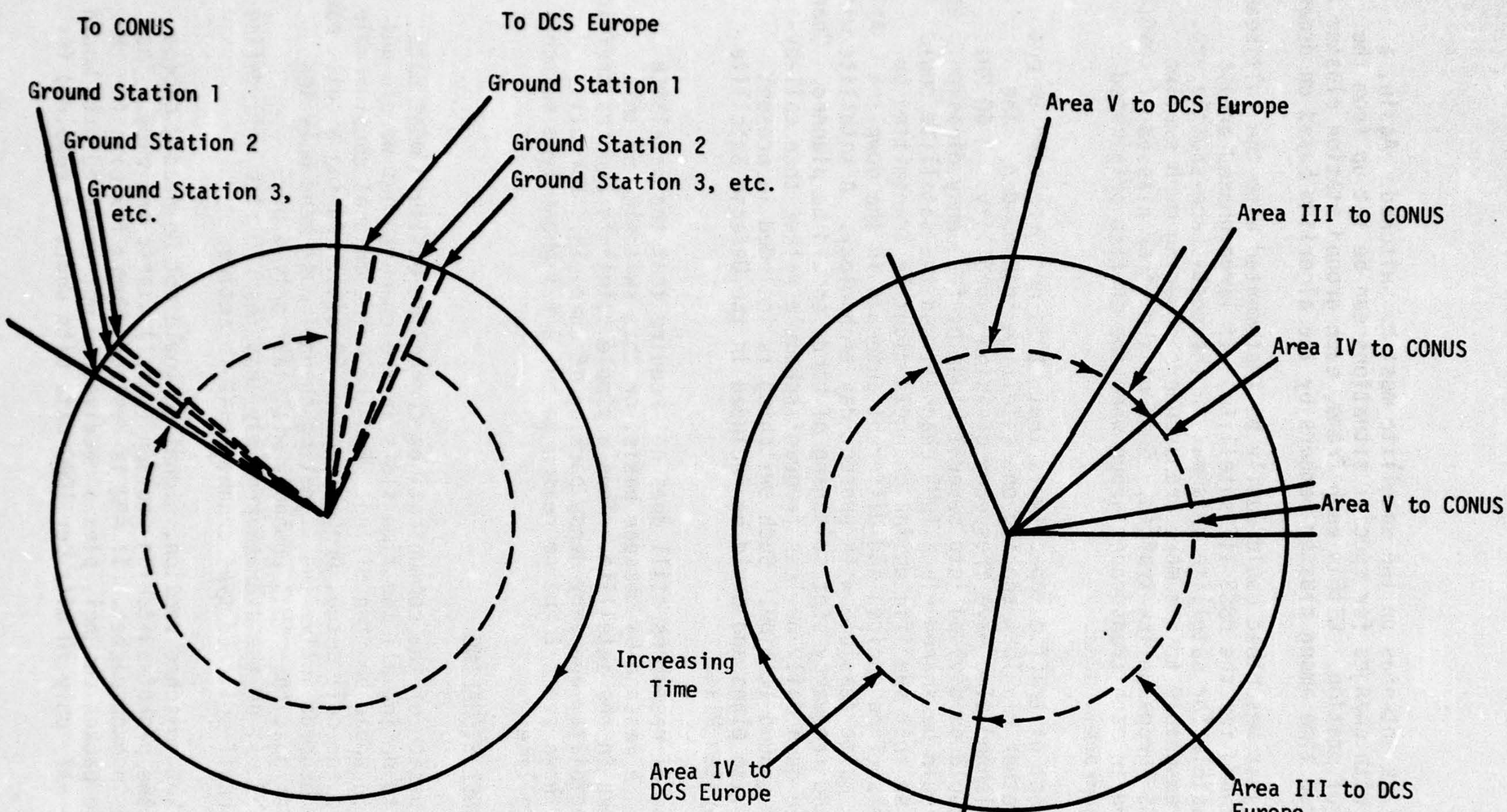


Figure 2. Atlantic Satellite Coverage of DCS Europe with Spot Beams



a. Area I Uplink

b. Areas III, IV, V Uplinks

Figure 3. Timing Diagram for TDMA Traffic

as well as downlink antennas on the satellite must be switched. Again, a diurnal pattern with changes for special situations can be set up from the spacecraft control station. Within each frame, each ground station cluster can share its allotted time among cluster members by the algorithm based on demand.

The system just described could easily be implemented with the multibeam antennas now planned for the DSCS III satellite. If large phased arrays should prove feasible for satellite antennas in the post-space-shuttle era, then it may be reasonable to use more transponders covering much smaller areas for the DCS Europe uplink traffic. Some of the other classes of traffic could be included in each transponder group when the traffic originated from the same geographic area.

Another aspect of traffic capacity is that it is not necessary to put all channels together via TDMA sharing one satellite transponder. The satellites now planned also have frequency division capability. A 60 MHz satellite band could be divided into several bands by frequency division. Each of these bands could be shared via a TDMA channel, and the satellite could switch channels so that specific uplink channels might be transmitted on different channels (frequencies) and different antennas in the downlink. All these things are quite feasible with present day technology. A satellite with both time slot and frequency slot switching of bands should be planned. Channels would be switched on a daily or less frequent schedule rather than call-by-call by a master ground station. Such switching is included in present commercial satellite plans and could be included in the Defense Satellite Communications System Plan.

This sharing of resources still does not require that the satellite read signaling on a message-by-message basis, or that switching on this basis be performed in the satellite. Thus a simple satellite handles traffic with extreme flexibility and very dense packing of channels. For all projected needs there seems to be no reason to put a telephone type switch on board the satellite.

3. COMMON CHANNEL SIGNALING

In the discussion of the communications channel we outlined what data need to be sent to define all the time slots in the channel, but we did not say how these data would be transmitted. For the voice channel considerable data are required for call setup, probably about 50 bits. During a call, each time the channel becomes active the signaling channel must send only the channel number designation. This probably will take only 4 or 5 bits to define. Thus, on the average probably less than 10 bits will define each voice or circuit-switched type channel that is active.

For the packet-switched section, signaling would not be needed except to define where the packet-switching section (burst) starts and ends. The routing would be in each packet. If ARQ is desired, then a few bits for the ARQ to define the packet channel, plus a received or not-received bit, would be required. In all, only 10 bits per 1000 data bits would be required for

signaling. The signaling could be put inband; that is, just before sending its burst of traffic each channel could send a signal burst. The problem here is that each ground station must monitor all traffic coming its way, look at the signaling bursts as they come in sequence sandwiched between the data bursts, and decide which data items are destined for that particular receiving ground station. This somewhat complicates the receiving hardware.

A better situation would be to have a common signaling channel into which all stations put their signaling. The timing of the signaling channel must permit the ground station to set its various memory registers to store the data as it arrives.

To determine the feasibility of a common signal channel, assume that the signaling channel must handle 1% as many bits as the communications channel (10 bits to the 1000-bit data word). Three transponders would be used in our proposed common user system. Therefore 3% of one transponder would be adequate to handle signaling for all channels. If we wanted an error correcting code to produce an actual data efficiency of about 50%, then a channel of about 6% of one transponder would be adequate for the signaling with error protection. Thus, if the basic transponder channel is 60 MHz wide, a channel of 3.6 MHz would be adequate to handle all signaling. This 3.6 MHz channel could be connected to a slightly broader beam antenna. It would cover all of the ground stations in DCS Europe and accept signaling from all of them. An alternative would be to time switch a narrow beam for the signaling channel. The time slot would be divided up so that each station gives its signaling before sending data through the main communications channel. If this arrangement were used, certain adjustments would have to be made in the various bit rates on the transponder that has the signaling channel because the communications channel would be narrower. These details would not be difficult to work out.

4. TIMING AND SYNCHRONIZATION

In a TDMA system it is essential that all stations that share the same time division channel have precise timing. Each station must know exactly when to start its burst to within a fraction of a bit so that the channels join one-another precisely at the satellite. For a 90 Mb/s rate, 1/10th of a bit is just over 1 nanosecond. Good crystal oscillators are available that will hold time to within 1 nanosecond with corrections every few seconds. With the system outlined, it is a simple matter to designate the first station in a frame as the master station. All other stations synchronize their clocks to the signal received from the master station. Each station also measures the distance to the satellite from the time required for its own signal to be received from the satellite. With a frame time of 1/64th of a second, correction occurs 64 times a second. In fact, with present day oscillator stability there should be no problem holding time better than 1/10th of a bit over many seconds. Thus, there seems to be little problem with maintaining exact timing among the stations that share the transponder on the uplink.

A protocol for designating the master station would have to be instituted. A backup master station would have to be designated so that it could take over

should the first designated master station fail, etc. Since all stations could hold the timing to a small fraction of a bit, there would be no problem handing off timing master synchronization in the event of a failure. A few bits are needed at the start of each burst of a PSK system to determine which phase is a zero and which is a one. Buffering could take up a fraction of a bit difference in timing from station to station. A code of a few bits to determine the phase reference at the beginning of the burst from each station should also set up the precise timing for the receivers. The slave stations could be synchronized to the master station in several ways, which have been discussed in the literature of synchronization of digital systems.

5. ENCRYPTION AND PREEMPTION

So far all the discussions have dealt with both voice and data traffic as clear traffic over a normal communications system. Encryption of some of the traffic makes little difference if the encryption is on an end-to-end basis. Channels could be set up by clear signaling, just as they are in our present secure voice equipment. If a key needs to be passed, an arrangement for communication with a central key generator could be made, or each ground station could have the ability to generate and pass keys to other stations when a secure call is made. The call setup will take a bit more time to get keys established but the setup would not be difficult. Encrypted voice traffic would proceed just as would the basic traffic. The only difference would be that secure traffic channels would have to be full-duplex all the time, because most of our encryption equipment sends random cyphered data even when the voice is silent. Thus, the voice silences could not be utilized for secure voice traffic. For record traffic the packets would be encrypted just as planned for AUTODIN II.

Since communications in the proposed system is always one station to several stations on each burst of the TDMA channel, a full link encryption scheme might be fairly complicated. A scrambler, difficult but not impossible to break, could be used. Then an enemy with only moderate resources would not have access to any of the traffic. Keys could be sent to all stations receiving the traffic on a regular or random basis by the central control station within CONUS. If this scheme were used, all signal and all data traffic could be encrypted. The links that must be secured against an enemy with considerable resources could then be individually encrypted on top of the overall bulk encryption. It is not a difficult scheme to work out; the only problem would be cost.

Preemption by higher precedence traffic is particularly easy to handle in this system since there are no tandem switches. Thus only the ground stations directly serving the calling and called parties are involved. The precedence of each voice call is easily class marked. The code for the calling number might well indicate the precedence. Then the called party's ground station knows the precedence of each call and acts accordingly. Data packets are sent in order by precedence. Simple formulas could be set to determine how long a data packet of a particular precedence is held before it preempts a voice call of lower precedence.

Anyone who has made routine AUTOVON calls of any length knows there is a reasonable probability of preemption. Still we make such calls. With the system of this TN a preempted call would not be disconnected and lost. If a segment of speech activity could not get into the TDMA burst because the allotted time was full of higher precedence calls and data packets, signaling could inform the receiving station. Then both receive and transmit stations could send a special tone to the respective terminal instruments. After a set period, say one second, the tone would go off and the parties could continue their conversation. A queueing arrangement could be made so that if a preemption were required soon after reinstitution of one preempted call, then a different call of the same precedence would be selected for temporary interruption. With this arrangement, calls at one precedence level below the nonblocking level would be blocked from entering the system. So that the phone user knows the problem, different busy signals could be used for blocking because of precedence and blocking because the called phone is in use. This is just like the trunk busy used on the commercial phone system.

6. VULNERABILITY TO JAMMING

The easiest way to jam a satellite communications system is to get a transmitter in the antenna coverage of the satellite and beam power up to the satellite on the uplink frequency. A high powered transmitter can completely swamp the satellite's regular transmission. Even a low power transmitter could be a nuisance jammer by introducing the equivalent of additional background noise. This could cause excessive errors in a digital satellite link.

The first principle in reducing susceptibility to jamming is to make the beamwidth of the satellite receive antenna as narrow as feasible. The proposed system keeps all stations that share an uplink antenna pattern in a close geographic area; thus a narrow antenna beam can cover the ground stations that use any particular transponder in a TDMA frame. A jammer would have to be in a restricted geographical area near the ground stations that use the satellite antenna, making this jammer easy to locate and silent. There is no need to make provision for location of such a jammer by the synchronous orbit communications satellite. Low orbit spy satellites that map radio frequency emissions worldwide are much better equipped for this task. The only problem is getting information from the intelligence community to the communications community and then to those who negotiate with or destroy the jammer.

For combatting a nuisance the best procedure is to go to some error correcting codes. There is nothing in the proposed system that would interfere with a coding scheme. The various coding implementations must be considered in advance so that the registers can be appropriately sized. A rate one half code is easy to implement by using two registers for every one used previously. The communications channel data rate would be cut in half. Since only half as many communications channels would be carried, only half the signaling is needed. Thus, the signaling channel can also have rate one half error protection. As more spread is put on the coding, the data rate goes down,

but the communications system principles remain the same. The system should be constructed to go all the way to a spread spectrum TDMA mode for heavy jamming environments. The spread spectrum modem could be a mode of the basic TDMA system.

V. TRANSITION

The transition from the present DCS to the system proposed in this report can take place gradually with the various new techniques introduced one at a time. Present DCS planning provides for a transition from analog to digital transmission in Europe in the early 1980's. The AUTOVON and possibly AUTODIN switches are to be replaced by a switch (the AN/TTC-39 or a derivative thereof) that can handle both circuit switched and store and forward traffic. The AN/TTC-39 as now planned can handle analog traffic and digital traffic of various rates. The packet-swtiched, store and forward network AUTODIN II is planned for CONUS by 1980. AUTOSEVOCOM II, the 16 kb/s secure voice system, is planned for worldwide implementation eventually. At present the TTC-39 is considered as the switch for AUTOSEVOCOM II overseas.

In Table II above we see that most circuits (698 out of 769 voice and 264 of 297 data/record) are not in the common user network at present. If, as the system upgrades evolve, more users are brought into the common user networks, then the first stages of the system of this TN should be introduced at the common user switches. If the ratios continue as they are at present, then major user locations and/or critical transmission multiplex points are the places to begin introduction of the proposed system. The planned European Telephone System (ETS) presents another possibility as a starting point for implementation of the proposed system. Five major tandem switches are planned for Heidelberg, Stuttgart, Nuernberg, Ramstein, and Frankfurt. Each such switch is at a major user base, so both subscribers and trunks come into each physical office area. Adding record traffic between these points as data packets would make a reasonably sized network for an experiment.

Figure 4 shows the central tandem switch core of the ETS as proposed. The local base switches are shown attached. These are intermediate switches with both local subscribers and tandems from other bases. The numbers are taken from the most recent ETS sizing requirements. The interswitch trunks are four wire DCS circuits. When the Digital European Backbone is completed, these trunks will be part of our digital transmission facility. We present a scenario for phasing from the ETS to the integrated, satellite communications system of this TN.

The modern concept in electronic switching in a communications system with digital transmission is computer control of a time division switching matrix. The information flow within the switch should be in the same format as that of the transmission. Both 64 kb/s PCM and 16 kb/s CVSD are completely compatible. The only difference is register/buffer sizing. By proper hardware design, only a software change is required to convert a PCM switching system to a CVSD system. The register/buffers of a store and forward digital system, whether packetized or not, could also be built in a compatible technology. Depending on whether the AUTODIN I or II philosophy is used

either a local message distribution switch or a terminal interface processor will be needed at each large base. These message switches could be readily integrated with the telephone switch using the SENET concept of [1].

The next step from SENET is to utilize voice silences to increase the useful traffic flow. The first step is to add speech activity detection so that the switch control knows which channels are silent. Then the signaling must be changed to that of Table I. Since interswitch trunks are fixed in number, there would be no sharing of channels among different switches. Thus the length of each burst would be fixed. If there were not enough traffic to fill the frame, then there would be silent periods. The five switches would not each have a complete Table I. Each switch would only know about that traffic with which it was involved.

As a further simplification, tandem connections through the network of Figure 4 would probably not utilize voice silences. For example, suppose there is more traffic from Stuttgart to Ramstein than the 24 trunks (one 1.544 Mb/s line) will support. Then some of the traffic might be routed via Heidelberg provided Stuttgart-Heidelberg and Heidelberg-Ramstein capacity is available. Once a call is routed on such a tandem path, it should probably hold a full duplex trunk (time slot) full time to prevent intermediate blocking. The additional signaling and buffering required to pass speech activity detection through tandem switches is probably not worth the cost compared to the savings of transmission.

Once integrated switching with speech activity detection and silence utilization is proven in the terrestrial network, then the satellite can be introduced. The network of Figure 4 has only 486 interswitch trunks. Even with the added data service there would be no more than 500 interswitch trunks since data takes little capacity in an integrated network. The system described above has about 1000 channels on a satellite transponder. For the first phase of the program a single transponder of 30 MHz bandwidth could carry all the traffic plus the signaling for twice the communications capacity of the network of Figure 4 because of voice silence utilization. Since the stations are geographically close, a single spot beam antenna is all that is needed. In the satellite system all traffic goes source to destination with only one pass through the satellite. There are no tandem connections.

The first step in the conversion to a satellite system would be to use fixed time slot assignments for the stations. Next the stations could vary their assignment of burst time duration by a formula based on demand. Since almost all the requirement demand information of each station is contained in Table I there is no need to set up a terrestrial net for sharing this demand data initially. All that needs to be added to Table I is the number of calls that are off-hook but could not get service because of capacity limitations and the number of packets held. With these few extra numbers, precedence class must be included, the demand data is all in a modified Table I. Now the variable burst system based on demand can be implemented using only the satellite for communications.

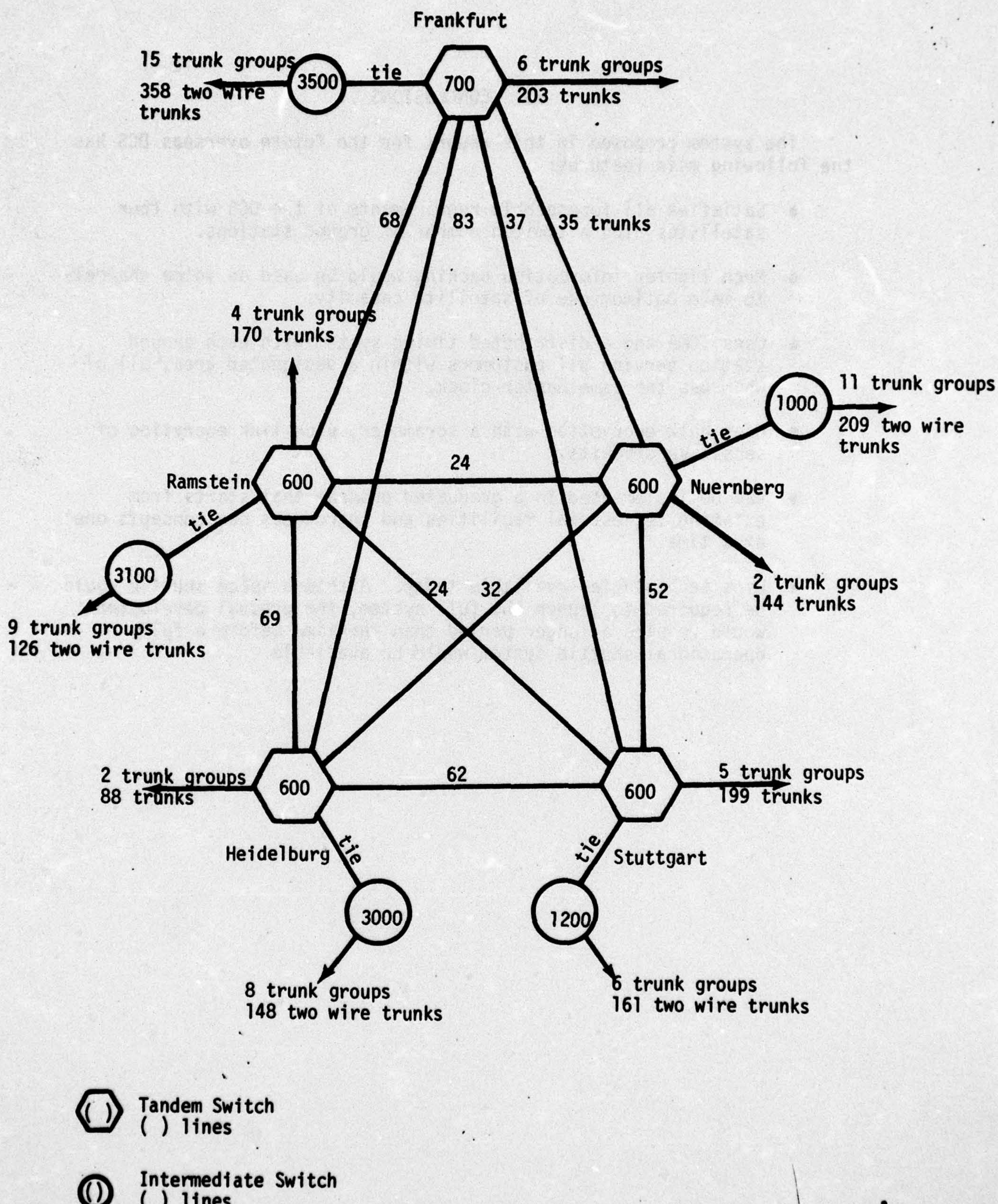


Figure 4. Proposed ETS System

VI. CONCLUSIONS

The system proposed in this report for the future overseas DCS has the following main features:

- Satisfies all foreseeable requirements of the DCS with four satellites plus a limited number of ground stations.
- Much tighter information packing would be used on voice channels to make optimum use of satellite capacity.
- Uses TDMA and a distributed timing system with each ground station serving all customers within a designated area, all of whom use the same master clock.
- Uses bulk encryption with a scrambler, plus link encrytion of sensitive circuits.
- Can be implemented in a graduated program that starts from existing terrestrial facilities and introduces new concepts one at a time.
- Uses technologies available today. Although space shuttle would be required to launch the full system, the gradual development would require a longer period than the time before a fully operational shuttle system would be available.

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